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Sedimentological studies of the "Ilha de Marchantaria" in the Solimões/Amazon River near Manaus

by

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1. Introduction

Because of their increasing importance for agriculture, animal farming and fishery, tropical wetlands have in recent years been the subject of an increasing number of ecological studies. The Amazonian floodplain or "Várzea", is an area which has until now, been only partially explored. Due to the constantly increasing population its importance for food production is growing. The relatively high fertility of the alluvial soils compared with the adjacent non-inundated land indicates that the Várzea is a suitable area for agricultural development projects (STERNBERG 1956; PETRICK 1978; JUNK 1982). Ecological conditions in the Várzea are very complex. Alternations between aquatic and terrestrial periods due to water level fluctuations in the Amazon have a strong influence on the as yet poorly understood biotic and abiotic processes (STERNBERG 1975; JUNK 1980). Sedimentation and erosion processes are among the most obvious effects of the Amazon on its floodplain through which the landscape is modified, producing a complex mosaic of biotopes. Differences in soil structure, fertility, water content etc. occur due to the selective action of watercurrents during sedimentation processes but despite their great importance, there is little data on sedimentation patterns and soil quality in the Várzea (CAMARGO 1954; ANDRADE 1956; STERNBERG 1956, 1960, 1975; SIOLI 1957; IRION 1978; PETRICK

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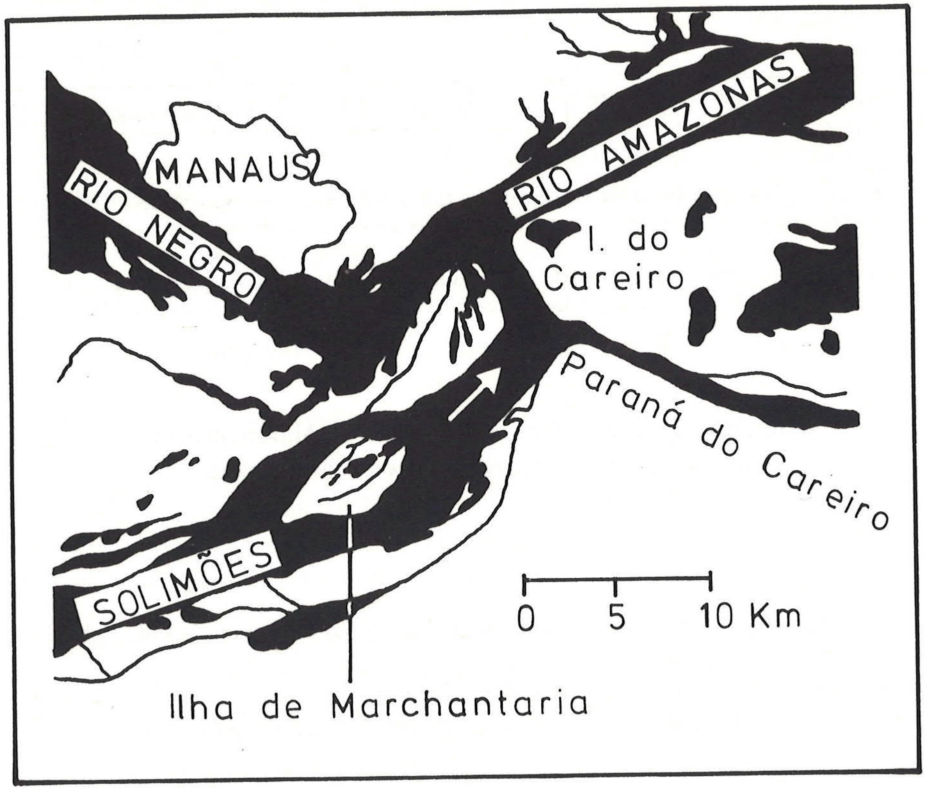

Fig. 1:
Map of the investigation area. Ilha de Marchantaria is also called Ilha dos Mouras

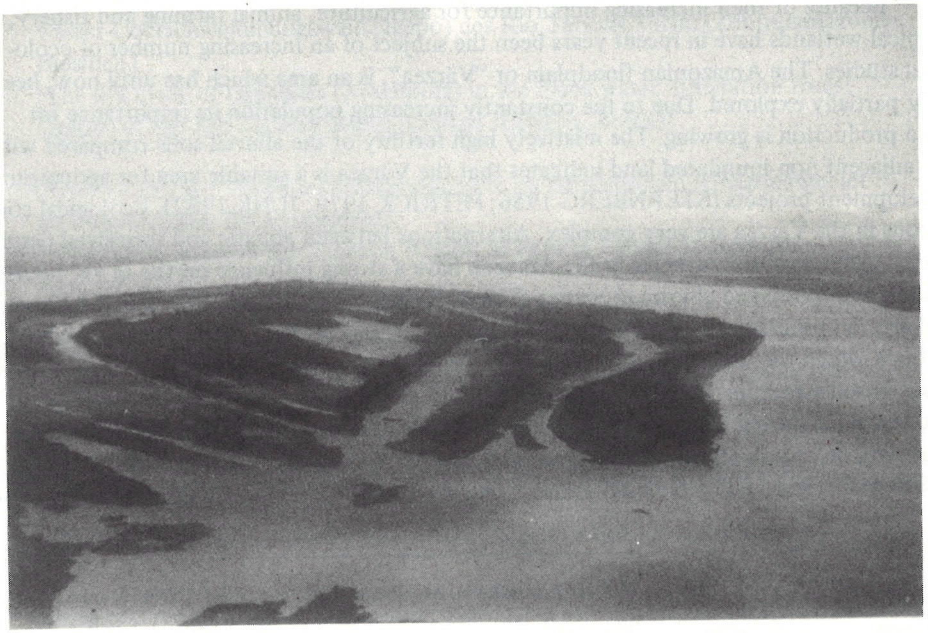

Fig. 2:
Aerial view of the Ilha de Marchantaria

1978). The following study provides information on the genesis and structure of the Ilha de Marchantaria (I. dos Mouras), an island in the Amazon (Rio Solimões) near Manaus.

2. Morphology of the Amazonian Várzea

The Várzea is a complex system of floodplain lakes, backwaters, river-channels, levees, islands, channel bars, etc. It extends over the Amazon valley which was formed during glacial times and filled, during the last 15000 years with sediments of mainly Andean and pre-Andean origin (IRION 1976a). In the area of the Ilha de Marchantaria the Amazon transports about 150 mg suspended solids per litre water (GIBBS 1967; IRION 1976b). In addition considerable amounts of sediments are transported as bed load. These have not yet been quantitatively assessed. The suspension load rates of the Amazon, coupled with its high water discharge and low channel slope, suggest that the Amazon would have a markedly meandering river bed. In fact the river shows hardly any tendency to form meanders. Occasionally, sinuosities with period lengths of 10's of kilometres (up to 40 km between 66 ° and 67 ° W) are formed. For long stretches of its course the Amazon is narrowed by Cretaceous, Tertiary and Pleistocene sediments which are not eroded easily. Among other causes for this are the frequent occurrence of solidified ground-water laterites (SOMBROEK 1966). In the area of the Ilha de Marchantaria, the Amazon valley, with the recent alluvia, is 10 to 15 km wide while the river itself is between 2 km and almost 6 km wide (Fig. 1). Ground water laterites have been observed on the northern shore, upstream from the island.

The high sediment discharge of the Amazon, its strong current, and the large annual fluctuations in water level are the chief phenomena responsible for the development of the Várzea (SIOLI 1957). On average annual differences in water level in the areas of the investigated island are about 9 m, with a maximum range of about 16 m. Level readings over the course of a year resemble sine curves, although the rise in water level between November and June is less pronounced than the fall between August and October.

At low water level banks are generally quite high and relatively unstable. "Terras caidas", (falling earth), is a well known term for those stretches of the river bank which in a matter of seconds can slide off into the water posing a serious threat to small crafts travelling close to the shore (BATES 1863).

3. Description of the study area

8 x 4 km in size (RADAM BRASIL 1972), the Ilha de Marchantaria is situated approximately 15 km above the mouth of the Rio Negro. The gradient of the middle Amazon (Solimões) is about 2 cm/km, although, the current velocity is high, with a maximum rate of about 3 m/sec. Island formation in the Amazon normally occurs in two ways. On the one hand alluvial land can be isolated by widening channels ("paranas" or "furos") to form islands; on the other hand islands are formed from sand bars in the river itself.

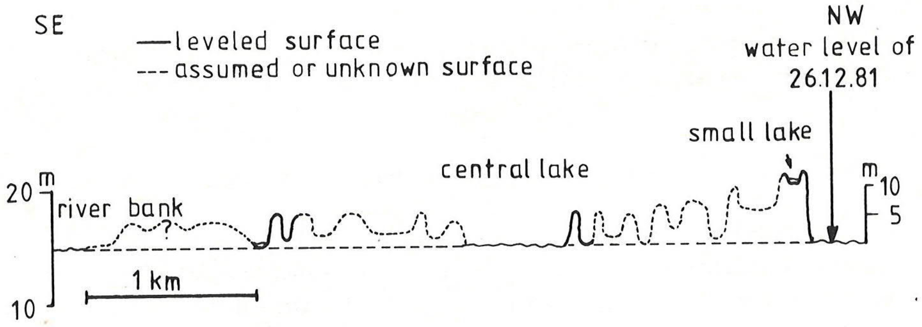

Fig. 3:
Schematic sketch of a cross section through the Ilha de Marchantaria

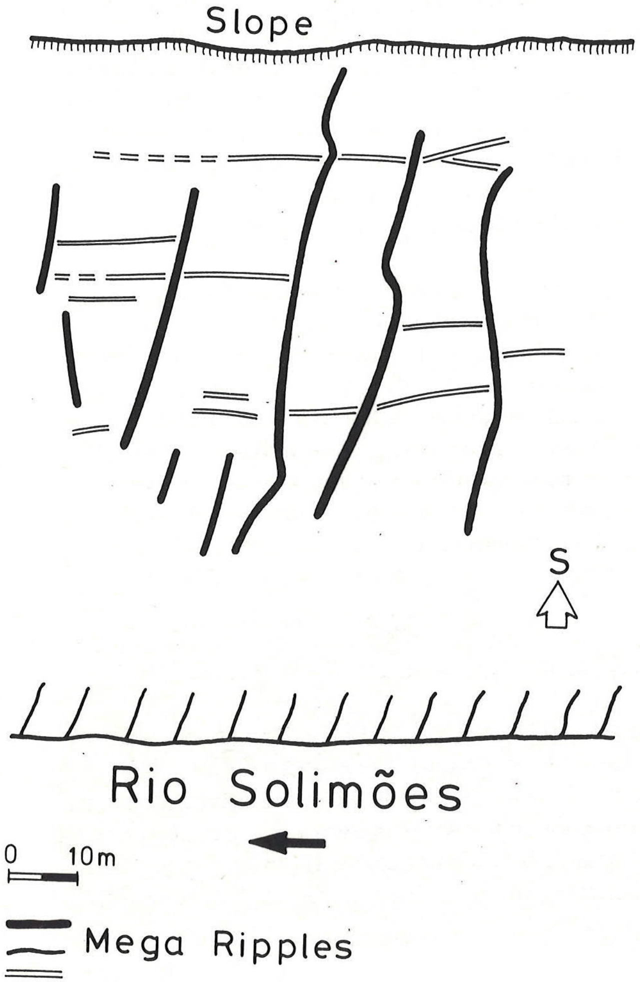

Fig. 4:
Schematic sketch of mega-ripples position on the studied channel-bar in the north of the island

The Ilha de Marchantaria belongs to the latter type; it was formed in the middle of the river where this was expanding.

Like the majority of the Amazon islands, the Ilha de Marchantaria is composed of ridges 10's of metres wide which extend over more than half the island (Figs. 2, 3). The ridges enclose a lake in the middle of the island, while smaller lakes also occur between the ridges. During low-water, some of the lakes dry out. The permanent ones are cut off from the Amazon. The western side of the island is a few metres higher than the other parts, and the ridges are less pronounced. At low-water, sandy bars are exposed on the downstream side of the island. During the period of rising water, the swales between the ridges are initially filled with water flowing in from the downstream side. The whole island is subsequently flooded when high water levels are attained.

4. Methods

Sediments from 20 selected areas of the island were sampled. In most places 2 - 3 ditches were cut in order to optain a vertical section through the sediment layers. Usually the ditches were 0.5 - 3 m deep and up to 5 m long. Soundings were taken at four places to a maximum depth of 6 m. It was possible to sample sediments from deeper layers in the steep banks (barrancos) on the river side of the island at low water period.

Grain-size analyses were done from about 140 sediment samples. The following grain-sizes were separated: < 2; 2 - 6; 6 - 20; 20 - 63; 63 - 90; 90 - 125; 125 - 160; 160 - 200; 200 - 250; 250 - 315; 315 - 500 and > 500 micron. Diffraction analyses, using Copper $K_{\alpha\ 1/2}$ radiation were carried out on a few samples. The chemical analysis was done by atomic absorbtion spectrometry.

5. Results

5.1. Channel bars

The sandy channel bars on the downstream end of the island are formed by mega-ripples (ripples with a wave length of more than 0.6 m). Figure 4 illustrates the distribution of mega-ripples in an area 100 x 100 m. Between the water level of Dec. 11, 1981 (17.80 m above sea level) and the base of the southern small cliff the channel bars rise 2.6 m while the cliff is 1.5 m high. The crests of the mega-ripples are approximately 15 m apart, the height of a single crest between 70 and 80 cm and the crest lenght in the investigated section 70 m. In addition to this ripple system there is a second irregularly situated one in between. This is more or less perpendicular to the first series of mega-ripples. Trenches reveal the transition of mega-ripple forsets and climbing ripples in the lower part of the ripple stratification (Fig. 5), a proof for mega-ripples (BOERSMA 1967). At the time of formation of this presumably contemporary mega-ripple system, water depth and flow velocity must have been quite high. Morphological superposition presumably occurred during surfacing. It is noticeable that in many mega-ripples morphology and texture do not correspond ("disconformity", REINECK and WUNDERLICH 1969). Presumably during high water considerable turbulence occurs on the sandy channel bars leading to numerous changes in the direction of discharge within the mega-ripple area. However mega-ripples with a downstream discharge direction can show divergence of up to 90 ° in their

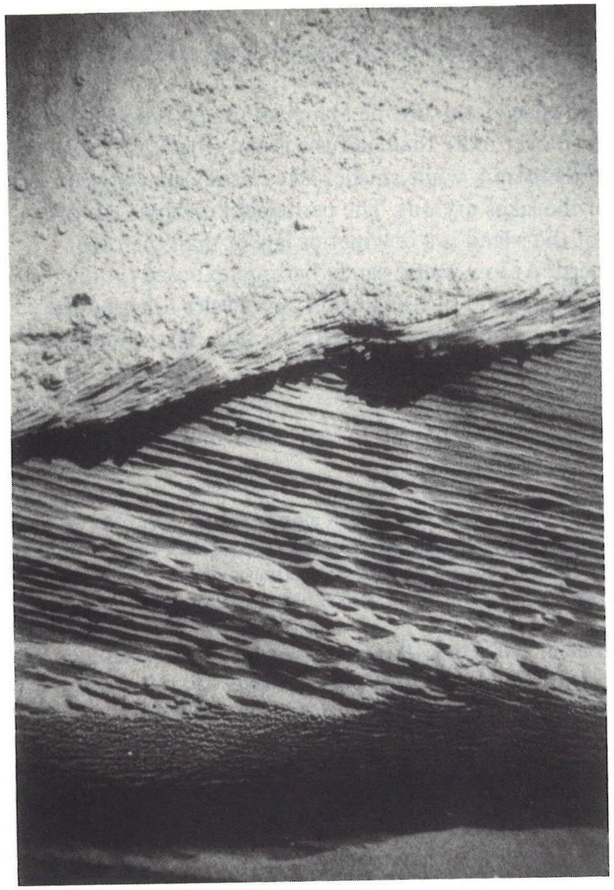

Fig. 5:
Climbing ripples at base of mega-ripples – forset beds

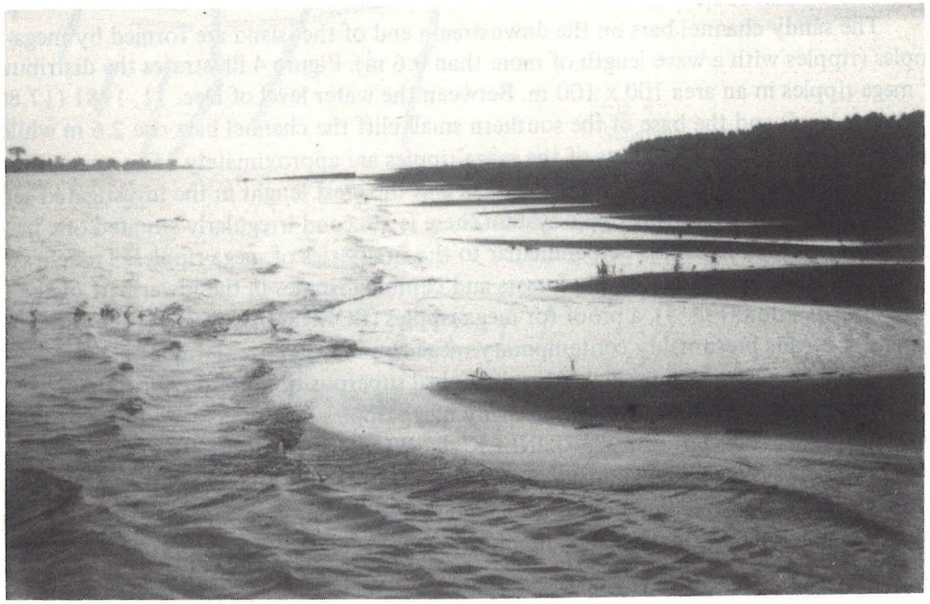

Fig. 6:
Levee-type formation of mega-ripples on a river bank during rising water

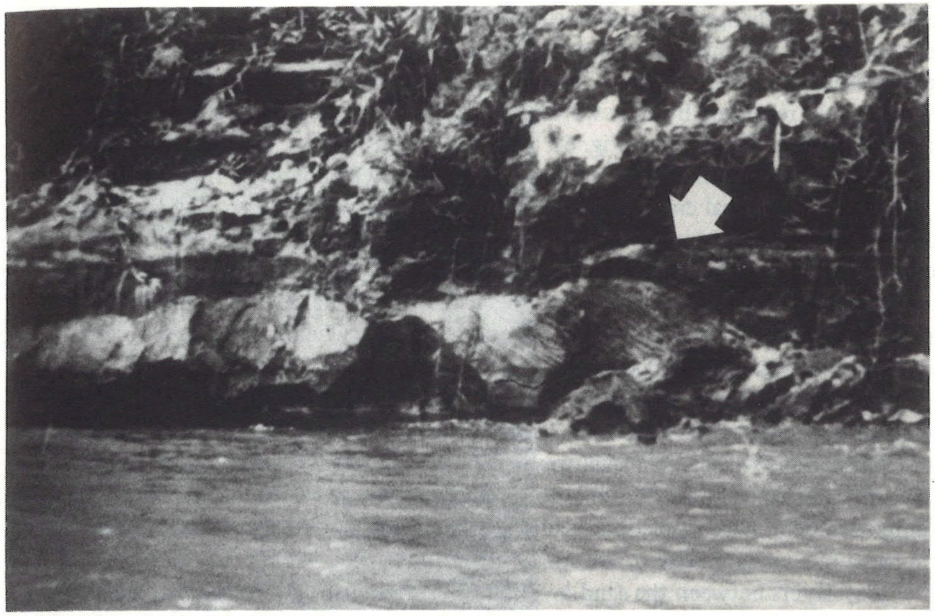

Fig. 7:
Completely preserved mega-ripple embedded in clay

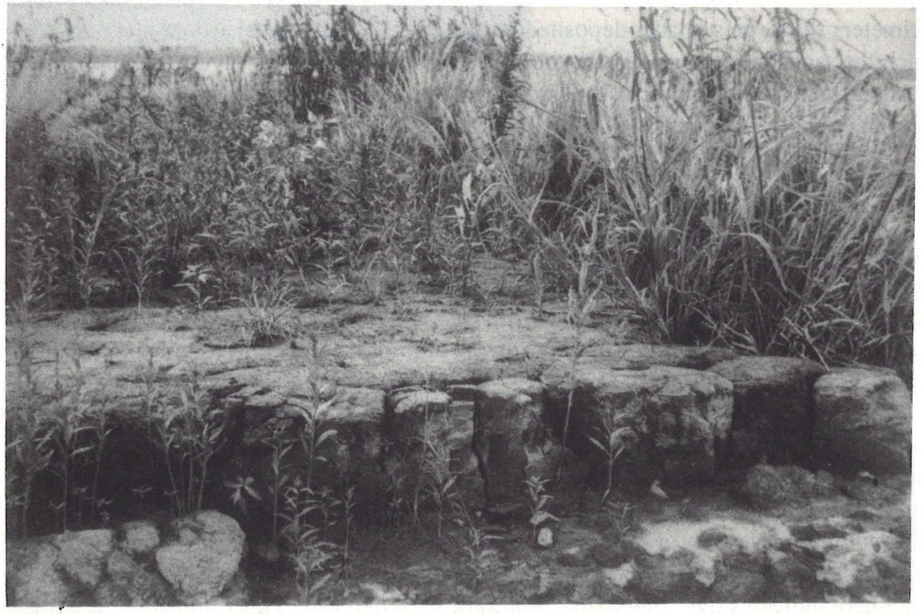

Fig. 8:
Clay broken into polygons by mud cracks; some polygons are eroded by underwashing

course, due to a change in island morphology (Fig. 2). Aeolian processes can occur during the exposure of the channel bar leading to a re-working of the surface structures (wind ripples, cross stratification due to formation of mini-ripples). The crests of mega-ripples are ultimately reformed by river wave action during an increase in water level. This can lead to levee-type formations (Fig. 6).

Locally, due to the presence of additional sediment, the mega-ripples build up thick layers of unidirectional cross beds. The rate of deposition may be so high that only a small portion of the sediment is re-worked by the process of mega-ripple migration. Due to erosion of the island point sand is re-suspended to a considerable extent; the already mentioned "terras caidas" may play an important role in this process, as is revealed by the sediment structures found off the northwest and southwest cliffs. The old sand layers are covered by new waves of mega-ripples. This leads to rapid accretion of the channel bars.

The sands of the channel bars have a median grain-size of approximately 200 µm, comparable to that of the river floor. However, variation in the colour reveals, that there are stratifications within the mega-ripples. The various shades of grey are a result of variations in water content, attributable to variations in the grain-size of each stratum. In one example studied, mega-ripple sand had a median grain-size of 185 µm, whereas a dark stratum had a median grain-size of 90 µm, with 17 % clay and fine silt.

Clay layers between the sand layers are of different origin. Transverse mega-ripples sometimes have intervening pools, which can cover areas of several 10 m^2. Occasionally water rich in suspended clay, flows into these pools, leaving behind layers of clay after evaporation or seepage. Of considerably greater importance are short periods of rising and falling water level when silt and clay can be deposited due to low current velocity. Mega-ripples on the north-west side of the island were totally covered by layers of clay several decimeters thick, presumably deposited during a rise in water level after a phase during which the sand fraction had already been deposited (Fig. 7). Clay layers that are exposed on the surface exhibit mud cracks. Underwash reactivates the sediment, and individual polygons can be transported as rubble or pebble (Fig. 8).

5.2. Ridges

During the low water period, the channel bars are colonized by a pioneer plant community, which has little impact on sedimentation rates, during the flood periods. The higher parts of the island adjacent to the sand bars, are covered with dense vegetation of perennial grasses, mainly *Paspalum fasciculatum* and *Echinochloa polystachya* (Fig. 3) accelerating sedimentation processes, reducing current velocity and stabilizing the ridges (JUNK 1973).

Approximately 100 m south of the river-bank on the northern shore of the island a particularly characteristic sequence of sediments was exposed in a 2 m deep excavation (Fig. 9). At the base an approximately 1.2 m deep band of mega-ripple stratification was found. Above this was a silt layer, probably deposited from a pool, as described above, followed by a succession of mini-ripple strata. In the hanging layer of these fine-grained sediments, the grain-size composition had a median of 70 µm. The sediment sequence found here indicates the "fining-up" typical of such deposits. This "fining-up" is explained by an enlargement of the island in the course of sedimentation, and a decrease in flow

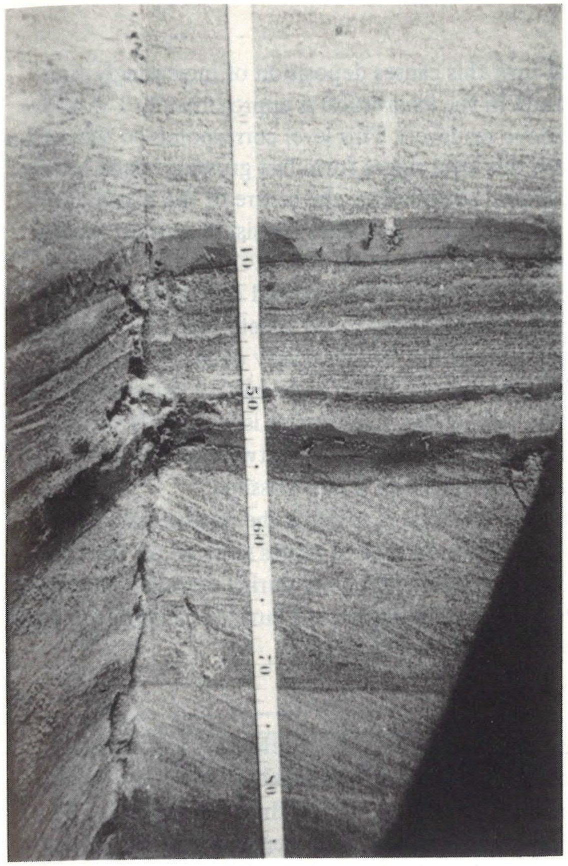

Fig. 9:
Transect into sediments above the landside border of the channel-bar. From top to bottom: Laminated sand, mud layers, mega-ripples

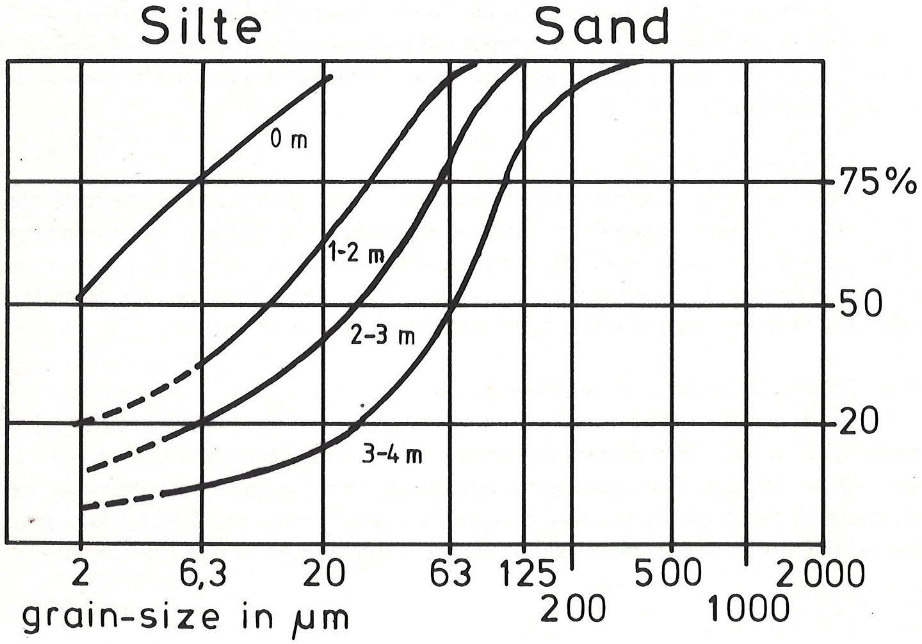

Fig. 10:
Grain size diagrams of sediments in a sounding through a swale

velocity in the area of the excavation. In turn this causes deposition of increasingly fine sand. The top layer of the mini-ripple strata in the excavation is approximately 1 m above water level of Dec. 26, 1981 (19,30 m above sea level). This level corresponds to the surface of some swales between the ridges. Above this level ridges form fast growing beach barriers (walls on the upper edge of the slip-off slopes) surrounding the centre of the island like arboreal annual rings, but open on one side (Fig. 2). The ridges consist of current ripples, occasionally interupted by silt/clay layers more than 1 m thick.

The top section of the ridges is usually formed by fine silt and clay with a median grain-size between 4 and 13 µm which is deposited under forest vegetation. The flow velocity in the area is low due to the persistent vegetation, which is very dense at the forest edges. Even at peak flood water depths barely exceed 3 m. The boundary between the fine silt/clay sediments and the underlying fine sand of the mini-ripples is frequently clearly defined with the thickness of the top fine silt/clay layer varying between 0.1 and 1 m. However a smooth transition between clay and fine sand is also possible.

In longitudinal profiles the ridges dip a few metres towards the downstream side of the island. The highest elevations on the island are formed of ridges situated on the upstream side of the island. Overbank deposition occurs here only during extreme flooding, decanting fine sand and silt according to the local vegetation and surface morphology. Silty clay is probably deposited during periods of falling water level.

5.3. Swales

The depressions between the ridges are flooded already at relatively low water level. As mentioned above, the water enters at the downstream side and deposits fine grained material according to the low flow velocity. The composition of the grain size (Fig. 10) in the profile of a swale indicates conspicuous “fining-up”. The lower part of the sediment presumably consists of mini-ripples deposited directly above channel bar mega-ripples. When the surface became the floor of a swale due to the formation of a ridge in front, only fine grained sediments, clay and silt were deposited reaching a depth of 2.5 m. In less protected zones coarser sediments settle in the upper two metres, but in general, the swale sediments are very fine-grained.

5.4. Central lake

Changes in ridge direction at their lower ends often generate closed basins at the centre of the islands in the Amazon River. They develop into lakes, which at least during low-water periods, are not connected with the Amazon. Clay/silt sediments with slight “fining-up” in their top layer are deposited in these lakes. On the Ilha de Marchantaria the central lake is called the Lago Grande and is the largest permanent lake on the island.

5.5. Profile of the upstream island point

Due to erosion of the upstream side of the island extensive profiles of the older sediments are exposed. Given favourable conditions, sediments might be consolidated into silt- and sandstone, without undergoing any changes in the sediment structure. A nine metres thick profile at the Northwest bank (“barranco”) was studied with this in mind. The base of the profile was at water level on Dec. 18, 1981 (18.48 m above sea level). The lowest

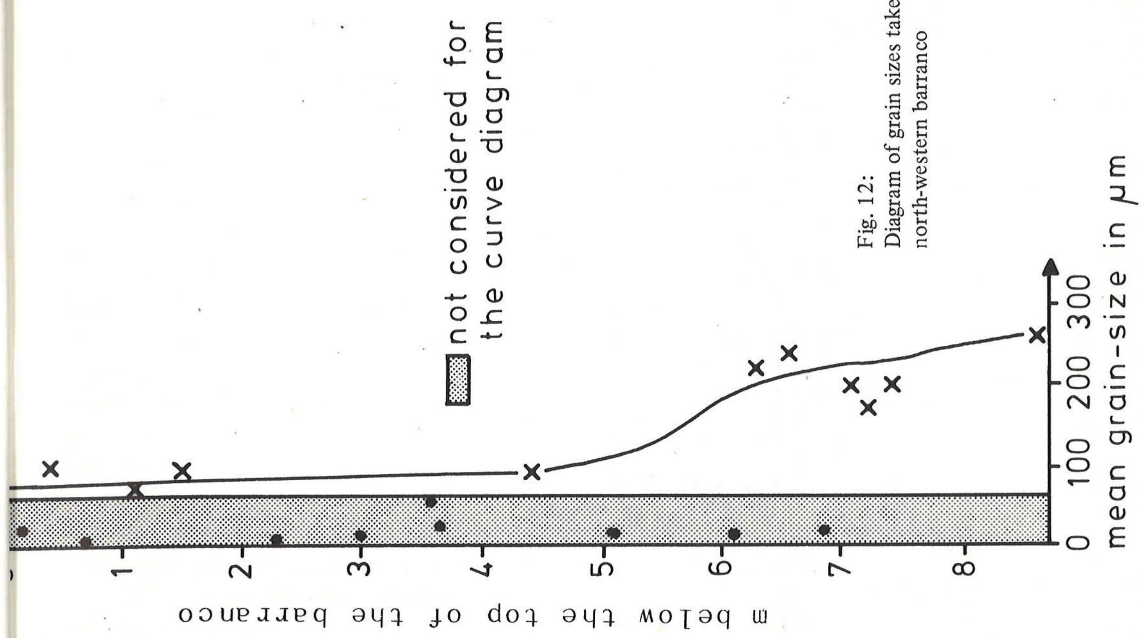

Fig. 12:
Diagram of grain sizes taken from a profile on the north-western barranco

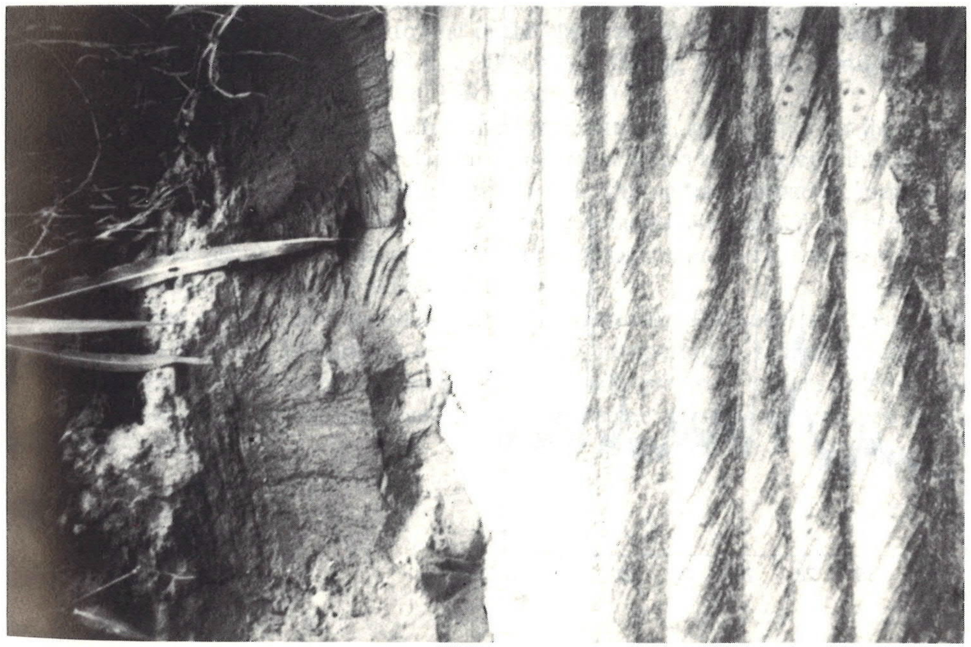

Fig. 11:
Stratification due to mega-ripples migration during sediment surplus

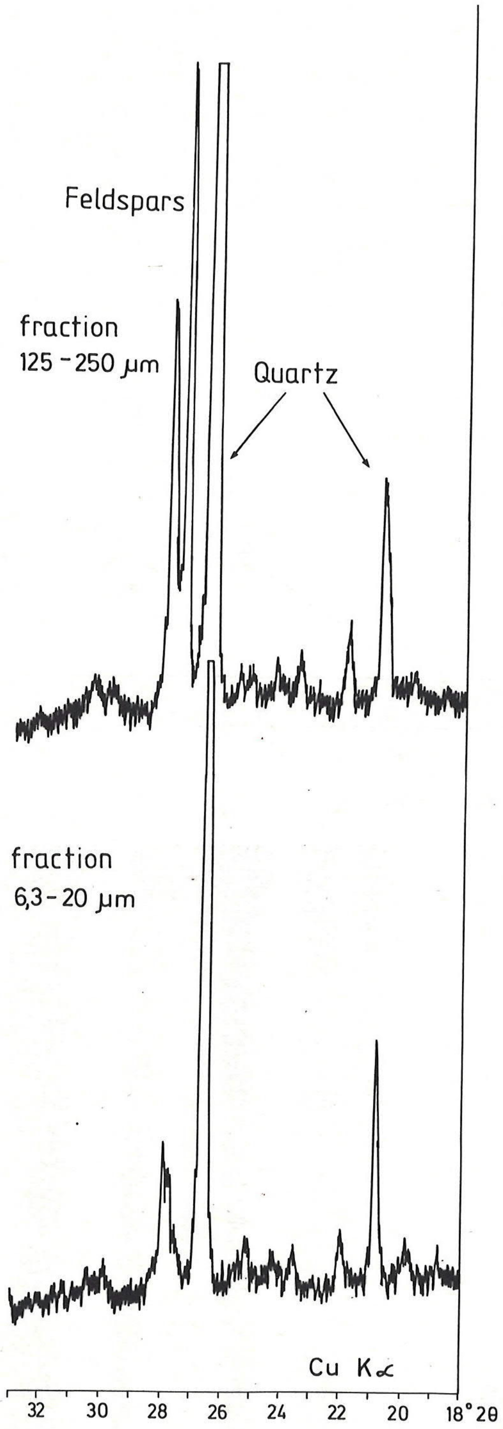

Fig. 13:
X-ray diagrams of coarse fractions of sediments from the island

2.5 m consisted of mega-ripple strata in which the individual strata were only approximately 10 cm thick (Fig. 11). This indicated as strong sediment supply on the channel bars on which the strata were formed. At one point a cross section of a mega-ripple (Fig. 7) was completely preserved. Clays in the mega-ripple valleys could have been formed in pools like the ones seen on the channel bar studied. They are followed by mini-ripple strata consisting of fine sands alternating with silt/clay up to the upper edge of the barranco. An especially important sequence of mini-ripple strata was observed 4 - 5 m above the river level which could be the top layer of a ridge with the subsequent 50 cm silt/clay layer on top. In this case the subsequent sediments in the hanging layer could only have developed during floods which would have covered the whole island. The grain-size composition of 19 samples of the barranco profile reflects the diversity of the structures building up the Várzea (Fig. 12).

5.6. Grain shape, mineralogical and geochemical composition of the Ilha de Marchantaria sediments

The sediments of the Ilha de Marchantaria are very uniform in their mineralogical and geochemical composition. No change in mineralogical composition in the sediments due to weathering is detectable indicating that the island is young, at most several centuries old. However, there is no doubt that the release of iron and manganese occurs to a considerable extent due to reduction and oxidation processes, and iron- and manganese-rich waters seep from the relatively coarse-grained and permeable mega-ripple strata situated in the barranco at low water period.

The sands of the Ilha de Marchantaria consist mainly of quartz with a smaller proportion of feldspars present (Fig. 13). STEIN (1979) found the following heavy minerals in Amazonian samples: hornblende, epidote, augite, hypersthene, apatite, titanite, granite, staurolite, zircon, turmaline, andalusite, disthene and baryte. The fine-grained fractions of the sediments mainly consist of montmorillonite, illite, kaolinite and chlorite (Fig. 14), in addition to quartz and feldspars. The chemistry of the clay fraction of the Amazonian suspension, supposingly very similar to that of the clay fraction of the island sediments, is as follows (in ppm). 2.800 Na, 18.600 K, 8.900 Ca, 11.700 Mg, 54.400 Fe, 804 Mn, 72 Cu, 160 Zn, 72 Li, 190 Cr, 16 Co, 40 Pb, 166 V and 5.500 Ti.

These sediments, which are rich in inorganic nutrients, are essential for the well-known fertility of the Amazon Várzea. In particular chlorite and to a lesser extent illite are under tropical weathering easily transformed clay minerals. During transformation, magnesium and potassium, together with a wide array of trace elements, are released and become available to the plants. In contrast to potassium and magnesium levels, sodium is low as a result of its low concentration in feldspars.

The vast majority of Amazon sediments originate from the Andes and their foothills (GIBBS 1967; IRION 1976b), but despite the long transportation, sediment rounding is minor. Minerals with a lamellar exterior are occasionally preserved in their original state (Fig. 15) and only grains of the gravel fraction show some rounding and polished surfaces (IRION 1976b).

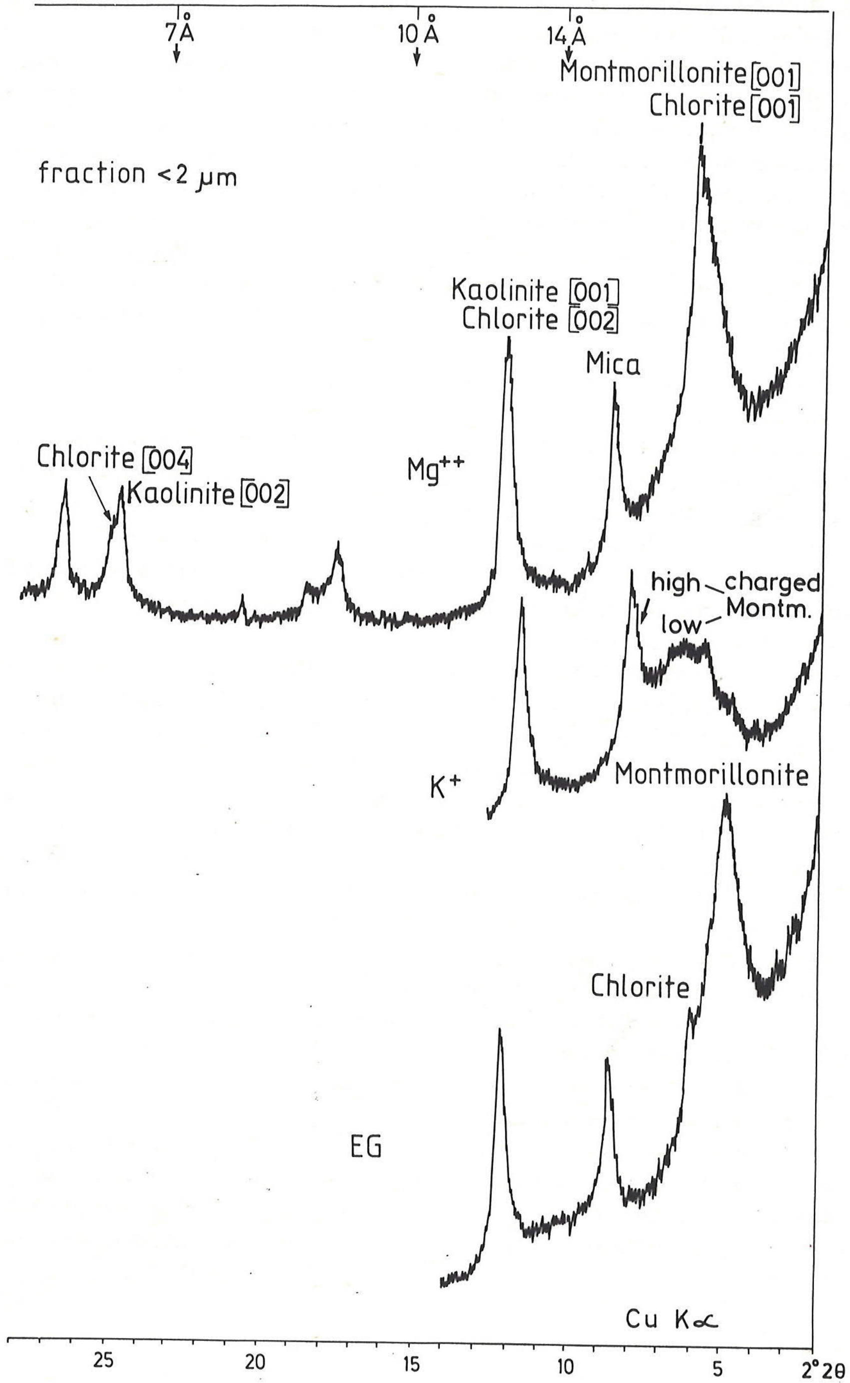

Fig. 14:
X-ray diagrams of fine fractions of sediments from the island

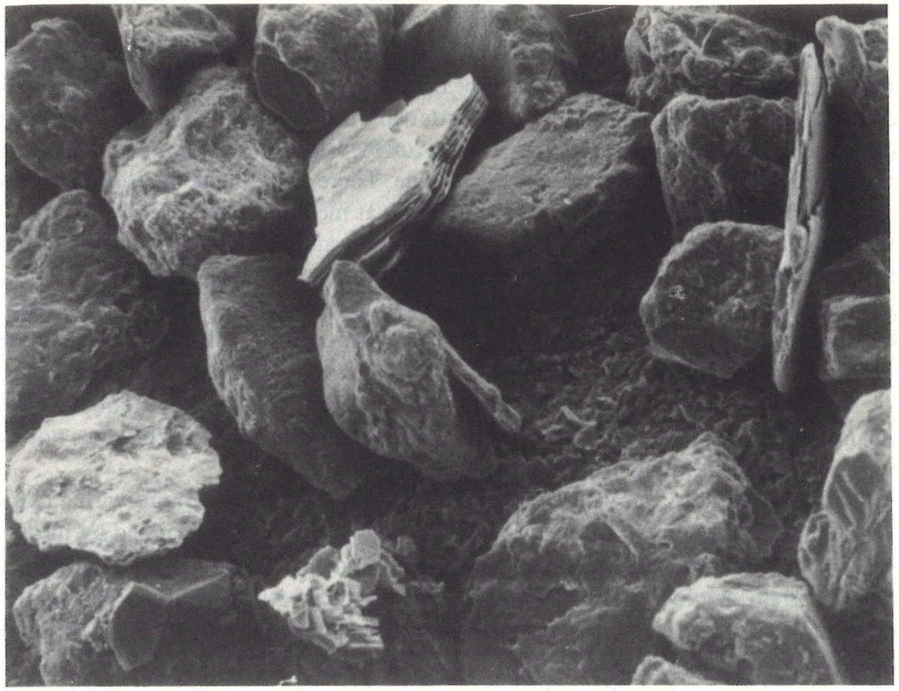

Fig. 15:
REM-photographs of Amazon coarse sediments

6. Discussion

Sedimentological studies have shown that the Amazon suspension load has only a very small gravel (fine gravel) content (SIOLI 1957; IRION 1976b; MEADE et al. 1979), and despite high flow velocities, the greater portion is composed of fine sand, silt and clay. With an average grain size of 0.2 mm or more, sands are at the lower range of grain diameters which form dunetype mega-ripples. Echograph profiles of the river bed demonstrate that channel bars and mega-ripples on the river floor determine the morphology. SIOLI (1965) describes an echograph profile taken 30 km downstream of the Ilha de Marchantaria where 6 m high mega-ripples with crest-distance of 600 m were measured. In contrast to the distribution of sands over the entire river bed, clays can only be deposited on the downstream side of a barrier. Although the current over the river bed is unidirectional, i. e. generally directed downstream, flow is sluggish and cyclic in the vicinity of bars exposed during low water levels. At high water levels one can assume that the channel bar mega-ripples are similarly active, like those on the river bed and the flow velocity is in any case more than 80 cm/sec.

The genesis of the Ilha de Marchantaria was probably initiated by the formation of a stable channel bar, on whose slip-off slope ever-widening sand bars began to accumulate. Ridges on such stable bars occur at various intervals, but more or less parallel to each other, and generally make up the surface morphology of the island. The island grows due to sand accumulation on the bars on its down-stream side. There is overbank deposition of finely-grained sediments in the swales between the ridges at medium water levels, in addition to the settling of fine sand and silt on the ridges at high water level. On the upstream side of the island especially high amounts of sediments are deposited during periods of extreme high water, because the water hits the island at full force being rich in suspended material. Thus the upstream point of the island is 5 - 6 m higher than the ridges on the down-stream side.

Sediment deposits of the Amazonian Várzea, are characterized by frequent contrast of coarse and fine sediment as shown in the barranco profile, although this does not exclude the development of "fining-up" in some of the layers.

A distinct pattern can only be detected for coarse sediments. Grains with a diameter of approximately 200 μm can only be found in the low lying layers, formed by mega-ripples. Above this level the maximum medians of sand are 100 μm (Fig. 12). The marked contrast in grain size found at almost any profile level, can ultimately be explained by the wide annual water level fluctuations. They allow the deposition of adjacent sediment layers with particle-sizes varying by a factor of more than 10.

Little is known about the sediment structure below the low water line. At the up-stream island point there is as expected a channel bar, while on the down-stream side of the island sediments with a median grain size of about 8 μm are deposited. It can be assumed that the down-stream part of the island rests on clay/silt layers many metres thick. When the island "drifts" a long distance down-stream due to erosion on the upstream part and sedimentation on its down-stream end it is conceivable, that a large part of its base consists of clay and silt. Crest height of the ridges increases from the interior to the exterior according to our grading measurements. The central lake is situated in the lowest part of the island. The probable explanation is that clays and silts become compacted in the central part of the island which is older and receives little new sediments. The plate-shaped structure of Amazonian islands has also been discribed by STERNBERG (1956, 1975).

Like other islands in the Amazon, the Ilha de Marchantaria is exposed to powerful dynamics. Sand bars are built up quickly on the down-stream end, whereas fast moving erosion of the upstream point of the island causes large areas covered with forest to fall into the river.

Comparison of maps of the island from the early part of this century with the radar chart of 1972 reveals considerable growth on the southern shore of the island, almost doubling the size of the island providing the older map is correct. The northern part of the island appears to be much older then the southern one.

Differences in extent of the flood period, the grain-size composition of the soil as well as the surface age result in the great diversity of biotops on the Ilha de Marchantaria and in the recent to subrecent Várzea in general.

7. Summary

Sedimentological studies on the Ilha de Marchantaria an island in the Amazon river near Manaus reveal the existence of four different structural main units.

A: Sandy channel bars consisting of giant ripples constitute deposits for the formation of islands or newly formed areas of the Várzea.

B: Gradual accumulation on the channel bars leads to the formation of point bar ridges which consist chiefly of small-scale ripples.

C: Between point bar ridges of different ages there exist swales. During rising water level the river water flows from the downward side into the swales where finegrained sediments are deposited.

D: Permanent lakes are formed mainly in the centre of the islands. During low water periods the lakes may be cut of from the river.

During high water periods when the whole island is flooded by the river, additional sedimentation takes place especially in the upstream area of the island. There is however, extensive erosion of the banks on the upstream side of the island. By erosion of the upstream end and sedimentation processes on the downstream end the island moves slowly downstream.

8. Resumo

Estudos sedimentológicos na Ilha de Marchantaria no Rio Solimões/Amazonas perto de Manaus indicam a existência de quatro diferentes estruturas principais.

A: Praias arenosas formadas por "ripple-marks" gigantes formam os primeiros depósitos para ilhas e áreas aluviais recém-formadas.

B: Acumulação graduada de sedimentos em forma de pequenas/"ripples" nas praias forma restingas.

C: Entre as restingas existem depressões. Durante as enchentes, a água do rio entra nas depressões pelas bocas nas pontas das ilhas situadas rio abaixo, depositando sedimentos finos.

D: Lagos permanentes existem normalmente no centro das ilhas. Durante a seca, eles podem ficar isolados do rio.

Durante as enchentes altas, a ilha esta sendo inundada inteiramente, sendo os sedimentos depositados principalmente na superfície da ponta situada rio acima, elevando-la. Porém, na Ilha de Marchantaria occorre forte erosão na ponta situada rio acima. Por causa de erosão nesta área e deposição de sedimentos na ponta rio abaixo, a ilha "migra" aos poucos rio abaixo.

9. Acknowledgements

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